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RESEARCH MEMORANDUM

ALTITUDE PERFORMANCE OF AN-F-58 FUELS IN J33-A-21 SINGLE COMBUSTOR

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Cleveland, Ohio

CLASSIFICATION CHANGED

To Confidential

By authority of J. W. Crowley Date 12-9-53

JH 12/12/53

CLASSIFICATION CANCELLED

Authority NACA R7 2442 Date 8/18/54

By MHA 9/1/54 See

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

April 8, 1949

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

ALTITUDE PERFORMANCE OF AN-B-58 FUELS IN 533-A-21 SINGLE COMBUSTOR

By Ralph T. Dittrich and Joseph L. Jackson

SUMMARY

An investigation was conducted in a single combustor from a 4600-pound-thrust turbojet engine to determine the altitude performance characteristics of AH-B-58 fuel. Three fuel blends conforming to the AA-F-56 specification were prepared in order to determine the influence of fuel boiling temperature8 and aromatic content on altitude performance. The performance of the three AH-F-58 fuels were compared with the performance of AH-F-32 fuel in the range of altitudes from 5,000 to 60,000 feet, engine speeds from 50-percent normal rated speed to military rated speed, and flight Mach number8 of 0.0 and 0.6.

The combustion efficiencies of three AN-F-58 fuels and AX-F-32 fuel were approximately equal up to altitude8 of about 50,000 feet. At higher altitude8 some differences occurred. At an altitude of 60,000 feet, 90-percent normal rated engine speed, and a flight Mach number of 0.6, a maximum arithmetical difference among the fuel8 of 14 percent occurred. The effect8 of fuel boiling temperature, a8 represented by a comparison of two AX-F-58 fuels differing in final boiling temperature by 30° F (560° to 590° F), on combustion efficiency were found to be negligible even at the high altitudes. At the high-altitude condition, the combustion efficiency of a hi&-end-point, high-aromatic M-F-58 fuel was greater thau that of the high-end-point, low-aromatic AN-F-58 fuel, the differences being more marked at a flight Mach number of 0.6 than at a flight Mach number of 0.0. These difference8 cannot be attributed solely to a change in aromatic content inasmuch as the boiling temperature8 in the middle distillation range of the two fuels also differ.

Although the altitude-operational-limit data are rather inconclusive, the operable speed range apparently tend8 to increase a8 the fuel boiling temperatures in the middle of the distillation range are increased.

INTRODUCTION

The potential availability of AN-F-32 fuel for jet-propulsion engines is relatively small because of limitation8 in boiling temperatures and composition. In order to increase the potential supply of fuel for jet-propulsion engines, AN-F-58, which ha8 wider specification limits, ha8 been proposed. A comprehensive program wae undertaken at the NACA Lewis laboratory to determine the performance characteristics of fuels conforming to AN-F-58 specification in current turbojet engine8 and single combustors from these engines.

In the single-combustor investigations, special attention was given to the influence of physical propertie of AN-F-58 fuel on combustor performance in order to determine whether the limitation8 on physical properties in the proposed specification are too liberal or too restrictive. The effect8 of boiling temperature and aromatic concentration within AN-F-58 specification on altitude performance in a single combustor from a 4600-pound-thrust turbojet engine are presented. Combustionefficiencies and altitude operational limit8 were determined in the range of altitude8 from 5,000 to 60,000 feet, engine speeds from 50- to 104-percent (military rating) normal rated speed, and flight Mach numbers of 0.0 and 0.6.

Comparisons of AN-F-58 fuel8 with an AN-F-32 fuel were also made at these conditions.

FUELS

Specifications and analyses for the AN-F-58 fuel8 and the AN-F-32 fuel used in this investigation are presented in table I.

Three fuels conforming to AN-F-58 specification were used. The first Of these (NACA fuel number 48-249) was a Uniform mixture Of several tank-car lot8 of AN-F-58 a8 received from the supplier. For purposes Of this investigation, this fuel, which boiled between 110° and 560° F end contained 19-percent aromatics, was considered a base stock. A second AN-F-58 fuel (NACA fuel number 46-258) was prepared by blending 92 percent of the base stock with 8 percent of , a number 3 fuel oil. The resulting blend boiled between 110° and 590° F and contained 19-percent aromatics. This blend is hereinafter identified a8 the high-end-point fuel. Comparisons of these two fuels (NACA fuel numbers 48-249 and 48-258) were intended to indicate the effect of boiling temperature on turbojet-engine performance.

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A third AR-F-58 fuel (NACA fuel number 46-279) was prepared by blending 79 percent of the base stock with 13-percent redistilled hydroformate bottoms and 8-percent number 3 fuel oil. The resulting fuel blend, which boiled between 110° and 590° F and contained 29-percent aromatics, approach88 the AH-B-58 specification limits of final boiling temperature and aromatic content. This blend is hereinafter identified a8 the high-aromatic fuel. Comparisons Of this fuel (NACA fuel number 48-279) with NACA fuel number 48-258 were intended to indicate the influence of aromatic content on turbojet-engine performance. The addition of the hydroformate bottoms, however, increased the boiling temperatures throughout most of the distillation range (of. NACA fuel numbers 46-258 and 48-279, table I) and therefore any influence this fuel may have on turbojet-engine performance may not be due solely to aromatic content.

Inasmuch a8 the silica-gel determination for aromatic content (tab18 I) is considered more reliable than A.S.T.W. determinations for AR-F-58 fuels, all aromatic concentrations referred to will be by the silica-gel method.

APPARATUS

A single-combustor assembly of 8 553-A-21 engine was connected to the laboratory air-supply and exhaust facilities (fig. 1) and was equipped with the necessary instrumentation to give total-pressure and temperature reading8 both upstream and downstream of the combustor (figs. 2 and 3). The downstream temperature measurements were obtained from 18 chromel-alumel thermocouples connected in parallel, thereby giving an instantaneous average exhaust-gas-temperature reading. These thermocouples were located in a plane approximately 28 inches from the fuel nozzle, a position approximately equivalent-to the turbine inlet of the engine. The fuel flow was measured by a f lowmeter, which wa8 calibrated far each fuel.

PROCEDURE

The operating conditions simulated engine operation over a range of engine speeds from 50-percent normal rated speed to military rated speed, altitude8 from 5,000 to 60,000 feet, and at flight Mach number8 of 0.0 and 0.6. Combustor-inlet air flow, pressures, and temperature8 and combustor-outlet gas temperatures (fig. 4) were calculated from the engine manufacturer's basic performance curves for a 533-A-23 engine.

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The operation of the combustor consisted Of adjusting the inlet air flow, pressure, and temperature for a specific condition and, after initiating combustion, the fuel flow was adjusted until the required combustor-outlet temperature was obtained. After sufficient time was allowed for the combustor and instrumentation to reach equilibrium, all pertinent data were recorded. If the required combustor-outlet gas temperature could not be attained, the condition was considered to be beyond the operational limit.

The combustor was disassembled and cleaned for each series of runs. (A series consisted of all altitude and engine-speed conditions for me fuel at one Mach number.)

Combustion efficiency is defined a8 the ratio of the enthalpy rise across the combustor to the heating value Of the fuel supplied and was calculated by the method described in reference 1.

DISCUSSION OF RESULTS

The data obtained in the investigation of the four fuel8 are shown in figure 5 a8 plots Of combustion efficiency against engine speed at various altitude8 and flight Mach number8 of 0.0 and 0.6. The altitude operational limit8 encountered for the four fuels are indicated on the figure.

The reproducibility of the data a8 shown by the duplicate data points in figure 5 was generally within 2 percent. At certain operating conditions, the reproducibility was poorer, especially at 50- and 60-percent normal rated engine speeds at altitudes of 30,000 and 40,000 feet.

Combustion efficiency. - For ease of comparison, data from the faired curves in figure 5 have been replotted in figure 6 to show the variation of combustion efficiency with altitude for the four fuel8 at two engine speeds.

At 90-percent normal rated engine speed end at both flight Mach numbers, the differences in combustion efficiency Of the four fuel8 at altitude8 below 55,000 feet were about equal to or within the limit8 of reproducibility of the data. At this speed and at an altitude of 60,000 feet, the maximum arithmetical difference8 in combustion efficiency among the four fuel8 were about 10 percent at a flight Mach number of 0.0 and 14 percent at a flight Mach number of 0.6.

At low engine speed and Mach number of 0.0 (fig. 6(a)), the arithmetical difference8 among the four fuel8 were negligible. At low engine speed and Mach number of *0.6 (fig.* 6(b)), however, the maximum arithmetical differences in combustion efficiency were about *7* percent at altitude8 of 40,000 and *50,000* feet and about *3* percent
1076 at low altitude.

At the high-altitude conditions where differences do occur (fig. *6)* the combustion efficiency for the base stock AX-F-58 fuel (48-249) and *for* the high-end-point AN-F-58 blend (48-258) were approximately equal. The conclusion is therefore drawn that under these conditions of operation the variation in boiling temperature8 represented by these two fuel8 ha8 a negligible effect on combustion efficiency.

At the high-altitude conditions, the combustion efficiency of the high-end-point, high-aromatic AH-F-58 blend (46-279) was greater than that of the high-end-point, low--tic AN-F-58 blend (48-258), the differences being more marked at a flight Mach number of *0.6* than at a flight Mach number of 0.0. The88 differences cannot be attributed solely to a change in aromatic content inasmuch a8 the boiling temperature8 in the middle distillation range of the two fuel8 also differ. At altitude8 lower than 60,000 feet, the combustion efficiencies of the high-aromatic blend, in general, tend to be lower than the combustion efficiencies for the other fuel8 investigated.

At the high-altitude condition8 (fig. 6), *the* combustion efficiencies of AN-F-32 fuel (48-306) were, In general, about the same a8 those for the high-aromatic AH-F-56 fuel (U-279).

<u>Altitude operational limits.</u> - The engine speeds at which altitude operational limits were encountered for the four fuel8 (fig. *5)* are summarized in table II with the minimum engine speeds investigated when no limits were reached.

No minimum operable speed limits were found for the four fuel8 at altitude8 investigated below 50,000 feet at a flight Mach number of 0.0. In these cases, engine speeds down to 50 percent of normal rated speed were simulated. At an altitude of 50,000 feet, limiting speeds were encountered for the four fuel8 in the range of engine speeds from *53* to *58* percent of normal rated speed and at *60,000* feet from *62* to *80* percent of normal rated speed.

At a flight Mach number of 0.6 (table II), minimum operable speeds were not encountered for the four fuel8 at altitude8

investigated below 60,000 feet. The minimum operable speeds for the four fuel8 at 60,000 feet varied between 60 and 66 percent of normal rated speed.

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When the base stock AX-F-56 fuel (NACA fuel number 48-249) is compared with the high-end-point AN-F-58 fuel (NACA fuel number 48-256) at a flight Mach number of 0.0 and altitude8 of 50,000 and 60,000 feet, it is seen that increasing the fuel boiling temperatures has extended the operable speed range. That is, the minimum operable speed has been reduced from 58 percent to 53 percent of normal rated and from 80 percent to 76 percent of normal rated epeed at altitude8 of 50,000 feet and 60,000 feet, respectively. At a flight Mach number of 0.6 and altitude of 60,000 feet, the operable speed ranges of these two fuels are the same.

The high-end-point AH-F-58 fuel (NACA fuel number 46-258) and the high-aromatic AN-F-58 fuel (NACA fuel number 46-279, table II) at an altitude of 50,000 feet and a flight Mach number of 0.0 had the same operable speed ranges. At au altitude of 60,000 feet and at both flight Mach numbers, the high-aromatic fuel had slightly wider operable speed ranges. Inasmuch as the boiling temperature8 in the middle distillation range (table I) of the two fuels (NACA fuel numbers 48-258 and 48-279) differ, the preceding effect on altitude limit cannot be attributed solely to the influence Of aromatic content .

At au altitude of 60,000 feet, the AN-F-32 fuel (NACA fuel number 48-306) had wider operable speed range8 than the AH-F-58 fuels.

Although the data for the *four* fuels in table II are rather inconclusive, the operable speed range apparently tend8 to increase a8 the fuel boiling temperature8 in the middle of the distillation range are increased. (See table I.)

SUMMARY OF RESULTS

From an investigation of the effects of fuel properties on altitude performance in a single combustor from a 4600-pound-thrust turbojet engine, the following results were obtained at simulated engine conditions of 5,000 to 60,000 foot altitude, 50-percent normal rated speed to military rated speed, and flight Mach number8 of 0.0 and 0.6:

1. The combustion efficiencies Of three AN-F-56 fuels and AN-F-32 fuel were approximately equal up to altitudes of about 50,000 feet. At higher altitude8 some difference8 occurred; at an altitude of 60,000 feet, 90-percent normal rated engine speed, and a flight Mach number of 0.6, a maximum arithmetical difference of 14 percent occurred among the fuels.

2. The effect8 of fuel boiling temperature, a8 represented by comparison of two AN-F-58 fuel8 differing in final boiling temperature by 30° F (560° to 590° F), on combustion efficiency were found to be negligible even at the high altitudes.

3. At the high-altitude conditions, the combustion efficiency of a high-end-point, high-aromatic AN-F-58 fuel was greater than thatofahigh-end-point, low-aromatic AN-F-56 fuel, the differences being more marked at a flight Mach number of 0.6 than at a Mach number of 0.0. These differences cannot be attributed solely to a change in aromatic content inasmuch as the boiling temperatures in the middle distillation range of the two fuels al80 differ.

4. Although the altitude-operational-limit data are rather inconclusive, the operable speed range apparently tends to increase a8 the fuel boiling temperatures in the middle of the distillation range are increased.

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National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Turner, L. Richard, and Lord, Albert M.: Thermodynamic Chart8 for the Computation of Combustion and Mixture Temperatures at Constant Pressure. NACA TN No. 1066, 1946.

2. Gooding, Richard M., and Hopkins, Ralph L.: The Determination of Aromatics in Petroleum Distillates. Paper presented before Mv. Petroleum Chem., Am. Chem. soo. (Chicago, Ill.), Sept. 9-13, 1946, pp. 131-141.

TABLE I - SPECIFICATIONS AND ANALYSIS OF FUELS USED

NACA fuel	Specifications AN-F-58	Specifications AN-F-32	Analysis AN-F-58 48-249	Analysis AN-F-58 48-258	Analysis AN-F-58 48-279	Analysis AN-F-32 48-306
A.S.T.M. distillation D 86-46, °F						
Initial boiling point	-----------	------------	110	110	110	336
Percentage evaporated						
5	-----------	------------	135	137	133	350
10	-----------	410 (max.)	157	157	164	356
20	-----------	------------	192	198	215	360
30	-----------	------------	230	248	273	365
40	-----------	------------	272	291	327	370
50	-----------	------------	314	332	370	375
60	-----------	------------	351	373	407	380
70	-----------	------------	388	410	437	387
80	-----------	------------	427	450	464	394
90	425 (min.)	490 (max.)	473	500	501	405
Final boiling point	600 (max.	572 (max.)	560	590	590	446
Residue, (percent)	1.5 (max.)	1.5 (max.)	1.0	1.0	1.0	1.0
Loss, (percent)	1.5 (max.)	1.5 (mar.)	1.0	1.0	1.0	1.0
Freezing point, °F	-76 (mar.)	-76 (max.)	C-76	C-76	<-76	------
Accelerated gum, (mg/100 ml)	20 (max.)	8.0 (max.)	2.9	12.4	17.3	0.0
Air-jet residue, (mg/100 ml)	10 (mar.)	5 (max.)	2.6	4.8	8.0	1.0
Sulfur, (percent by weight)	0.50 (max.)	0.20 (mar.)	0.03	0.04	0.04	0.02
Aromatics, (percent by volume) A.S.T.M. D-875-46T	30 (max.)	20 (max.)	17	17	26	------
Silica gel[a]	-----------	------------	19	19	29	15
Specific gravity	-----------	0.850 (max.)	0.769	0.775	0.806	0.831
Viscosity, (centistokes at -40 °F		10.0 (max.)	2.67	2.94	4.26	------
Bromine number	10.0 (max.)	3.0 (max.)	13.8	13.3	12.4	------
Reid vapor pressure, (lb/sq in.)	14.0 (max.) 5-7	------------	5.4	5.1	4.8	------
Hydrogen-carbon ratio	-----------	m---s--w----	0.163	0.161	0.150	0.154
Net heat of combustion (Btu/lb)	18,200 (min.)	------------	18,640	18,690	18,480	18,530
Hydrocarbon analyses (percent by volume)						
Single ring -tics			15.0	15.2	14.8	------
Fused ring aromatics			3.0	4.1	12.8	------
Unfused two-ring aromatics			0.5	1.5	1.4	------
Olefin			7.1	6.2	5.3	------
Nonaromatic cyclo-paraffin ring			15.7	16.7	14.3	------
Nonaromatic paraffin and paraffin side chain			58.7	58.3	51.4	------

[a]Determined by modified method of reference 2.

TABLE II - ALTITUDE LIMITS AS DETERMINED BY

MINIMUM OPERABLE ENGINE SPEED

NACA fuel number → / Altitude (ft) ↓	Engine speed (percent normal rated)			
	AN-F-58			AN-F-32
	48-249	48-258	48-279	48-306
	50-percent distillation temperature, °F			
	314	332	370	375
	Flight Mach number, 0.0			
40,000	[a]50	[a]50	[a]50	[a]50
50,000	58	53	53	53
60,000	80	76	71	62
	Flight Mach number, 0.6			
50,000	[a]50	[a]50	[a]50	"50
60,000	66	68	63	60

[a]No limit, minimum engine speed investigated.

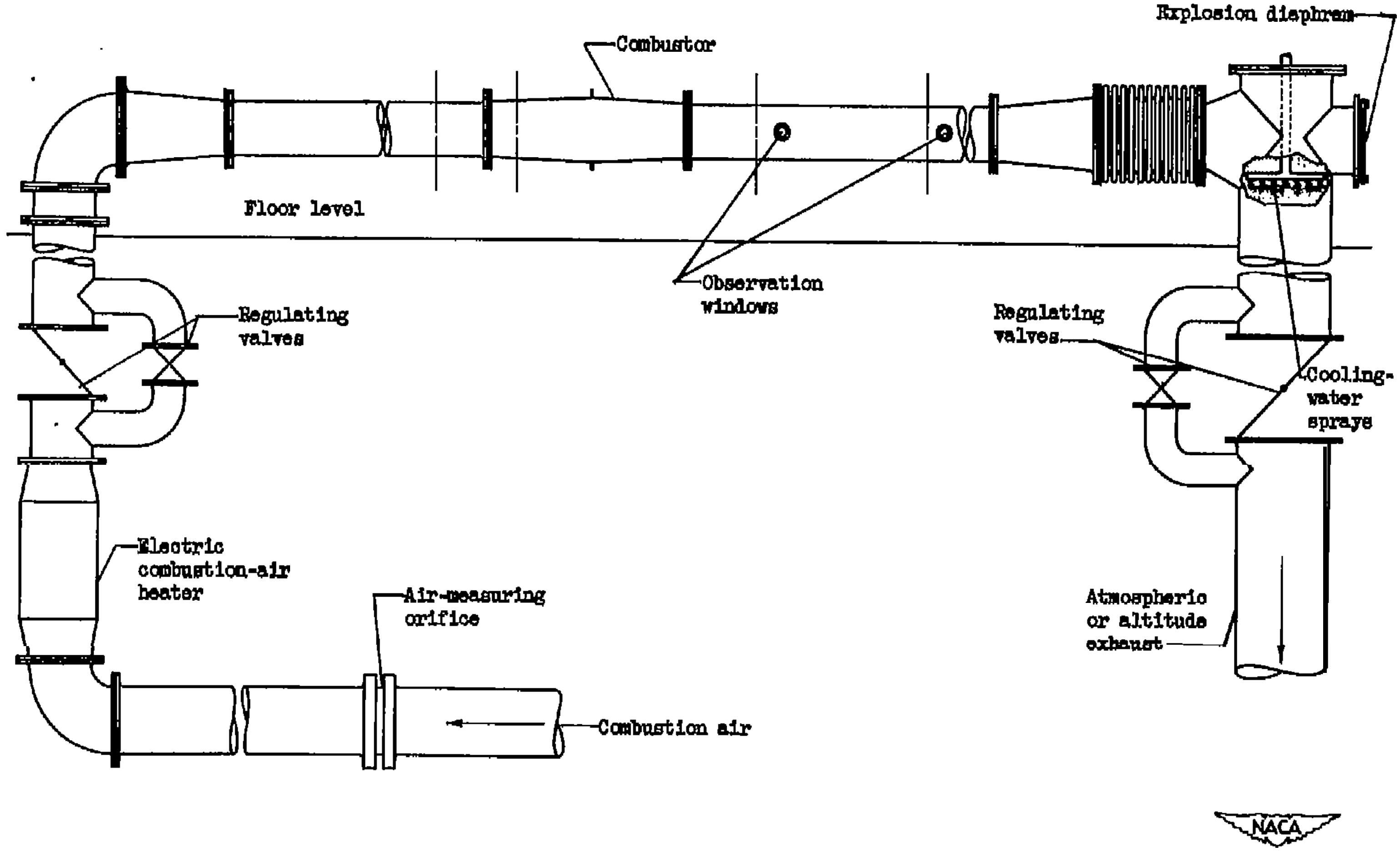


Figure 1. - Single-combustor installation showing inlet and outlet ducting.

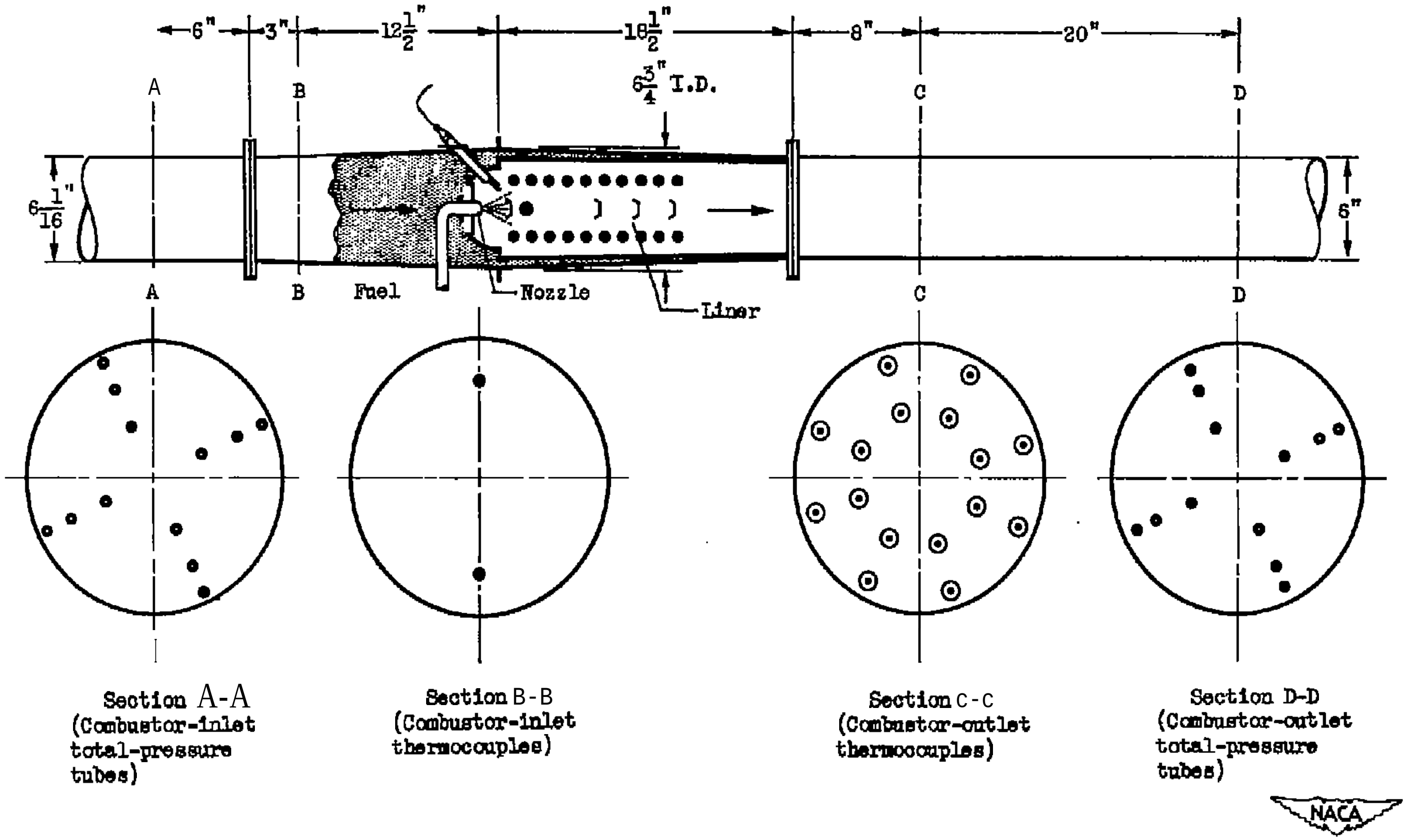
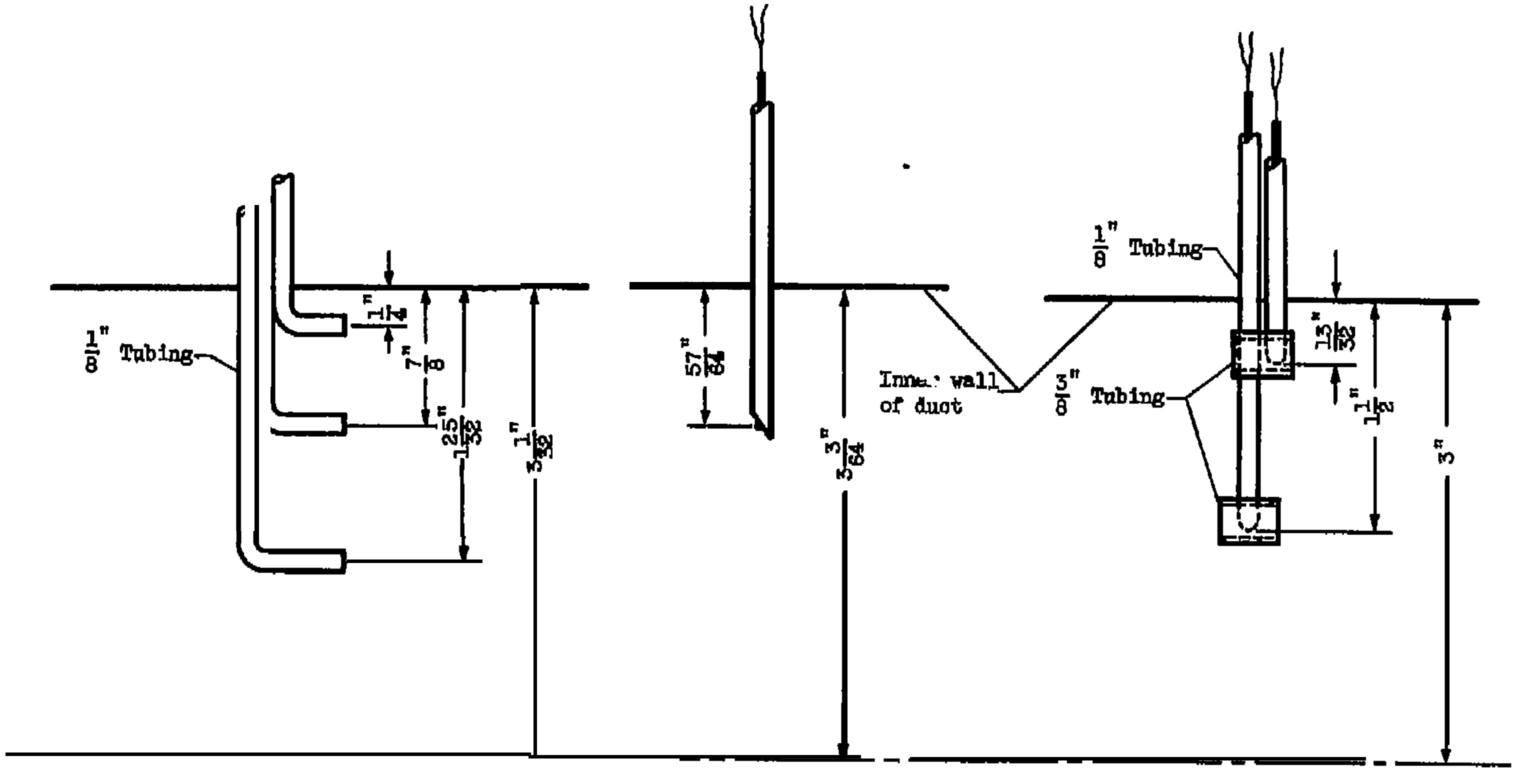


Figure 2. - Detailed sketch of single-combustor installation showing arrangement and location of total-pressure tubes and thermocouples.

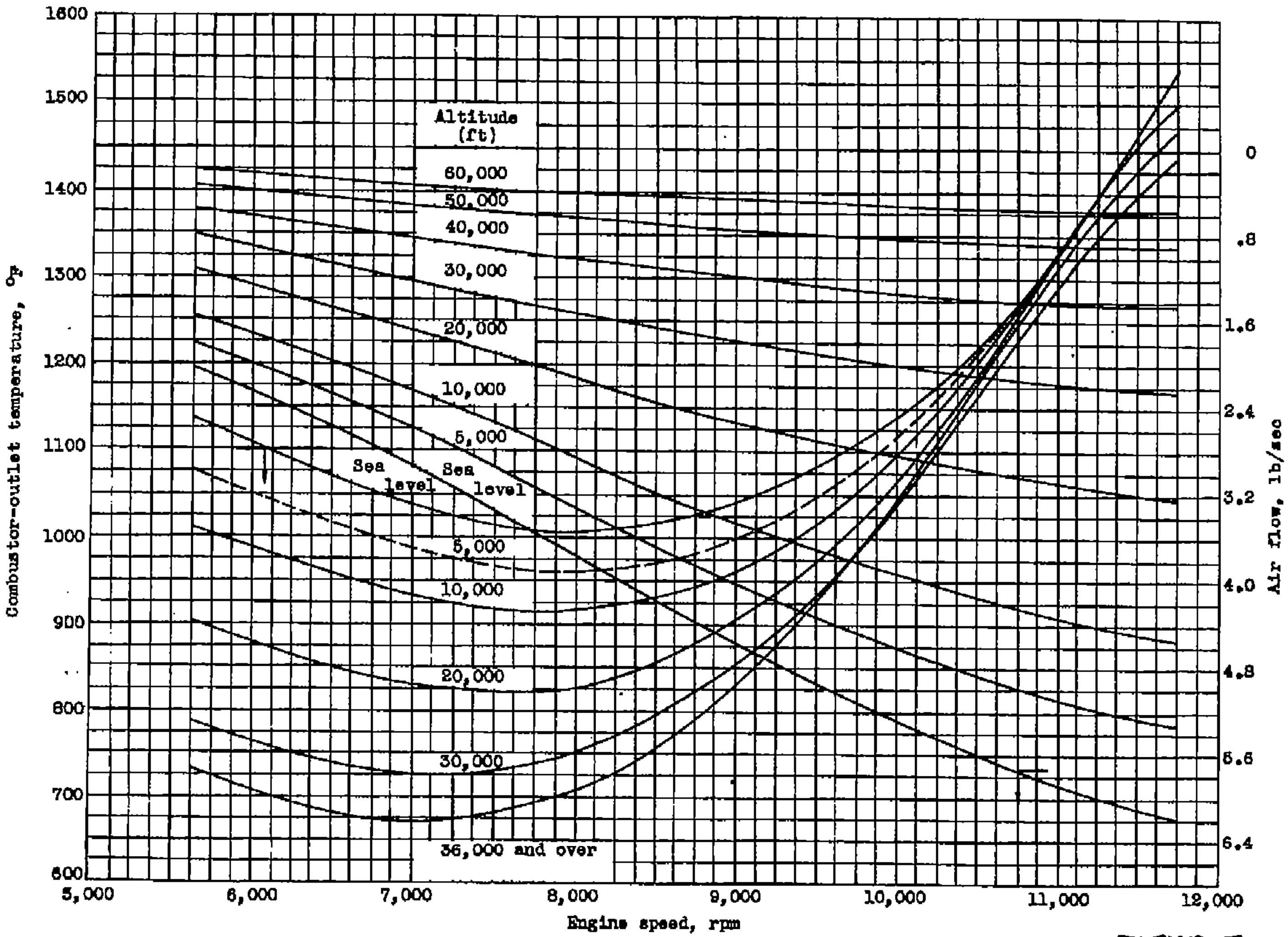


Total-pressure rake (sections A-A and D-D)

Iron-constantan thermocouple (section B-B)

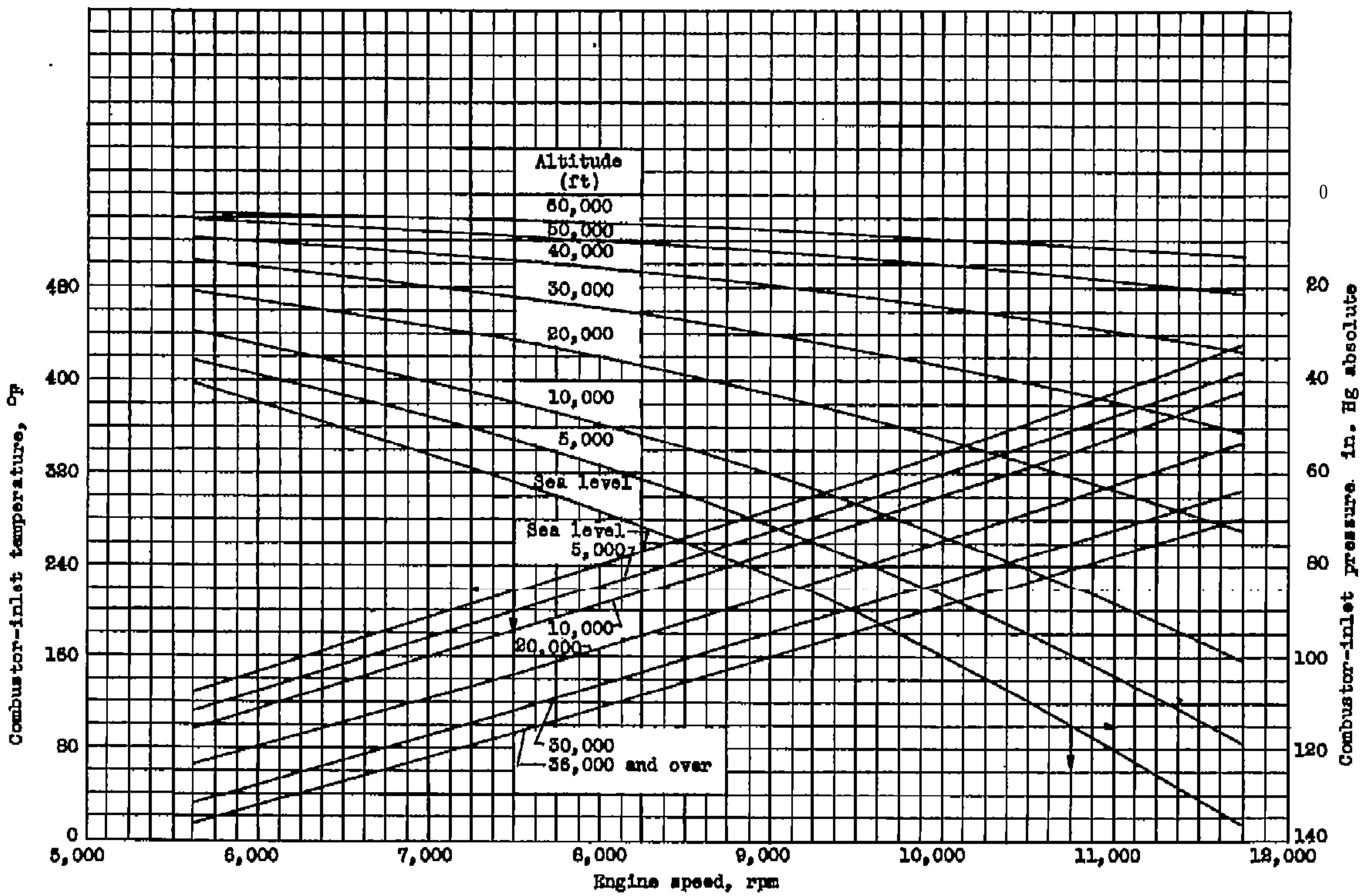
Chromel-alumel thermocouples (section C-C)

Figure 3. - Design details of total-pressure rakes and thermocouples.



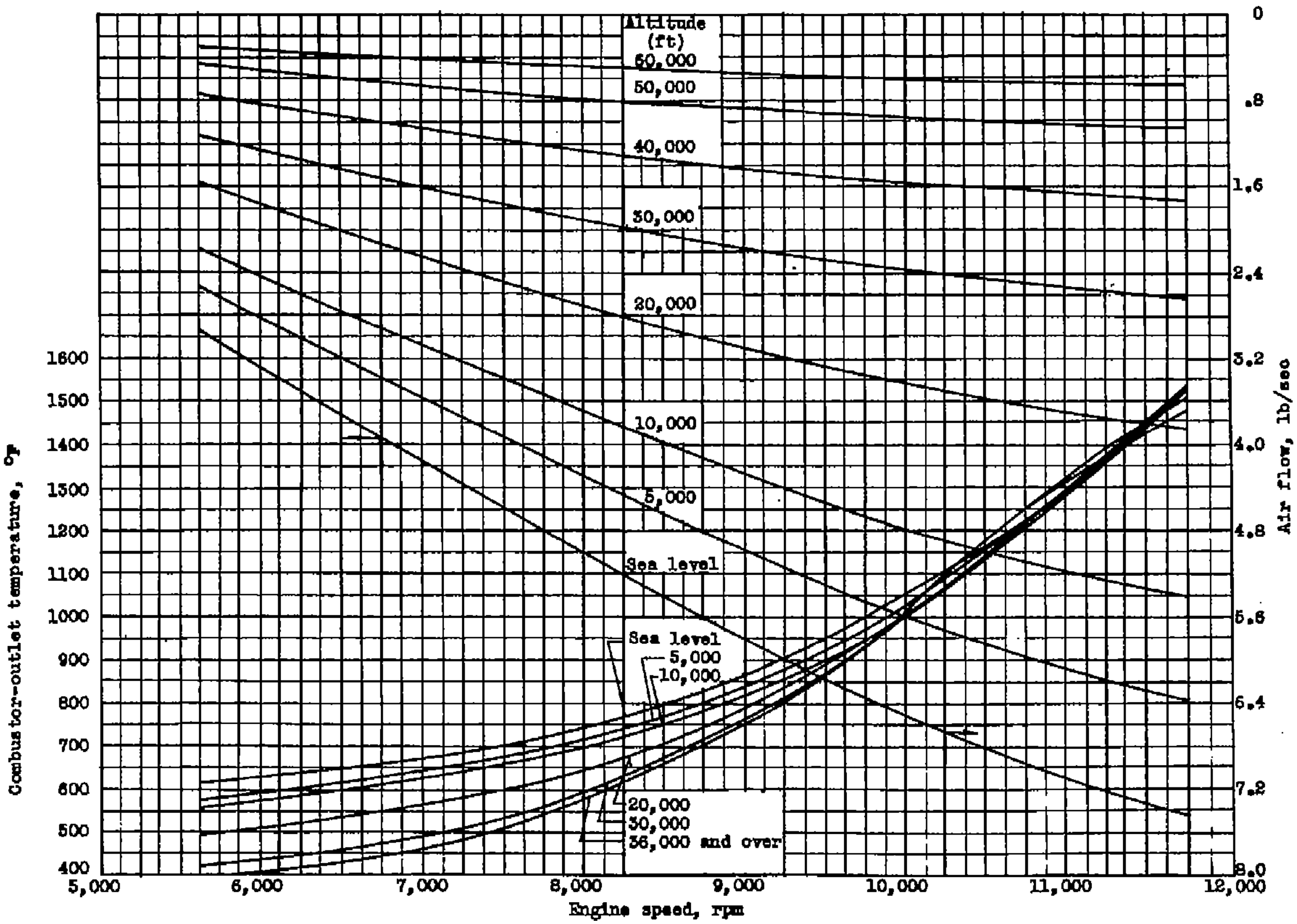
(a) Outlet temperature and air flow. Flight Mach number, 0.0.

Figure 4. - Control chart for single combustor investigated.



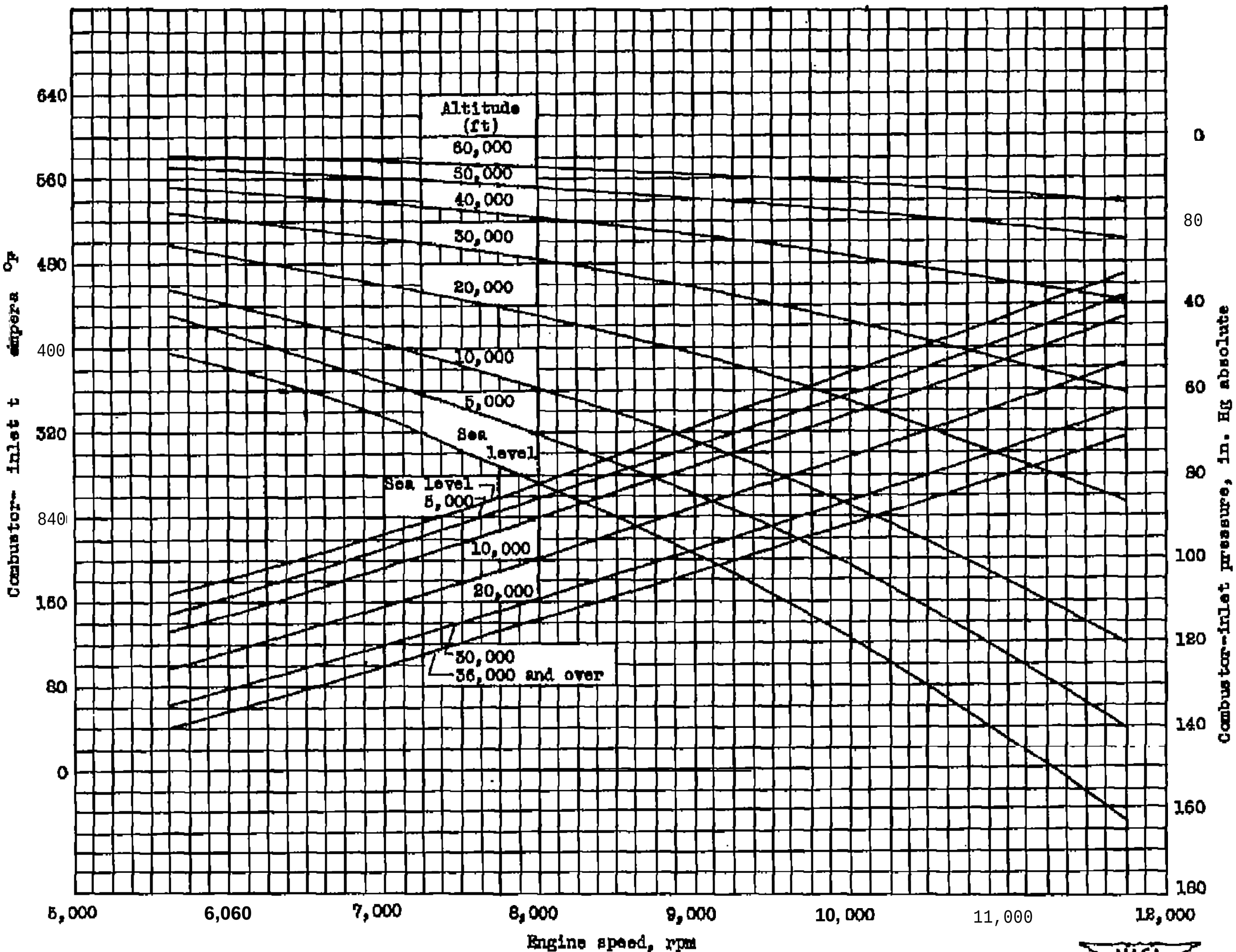
(b) Inlet temperature and pressure. Flight Mach number, 0.0.

Figure 4. - Continued. Control chart for single combustor investigated.



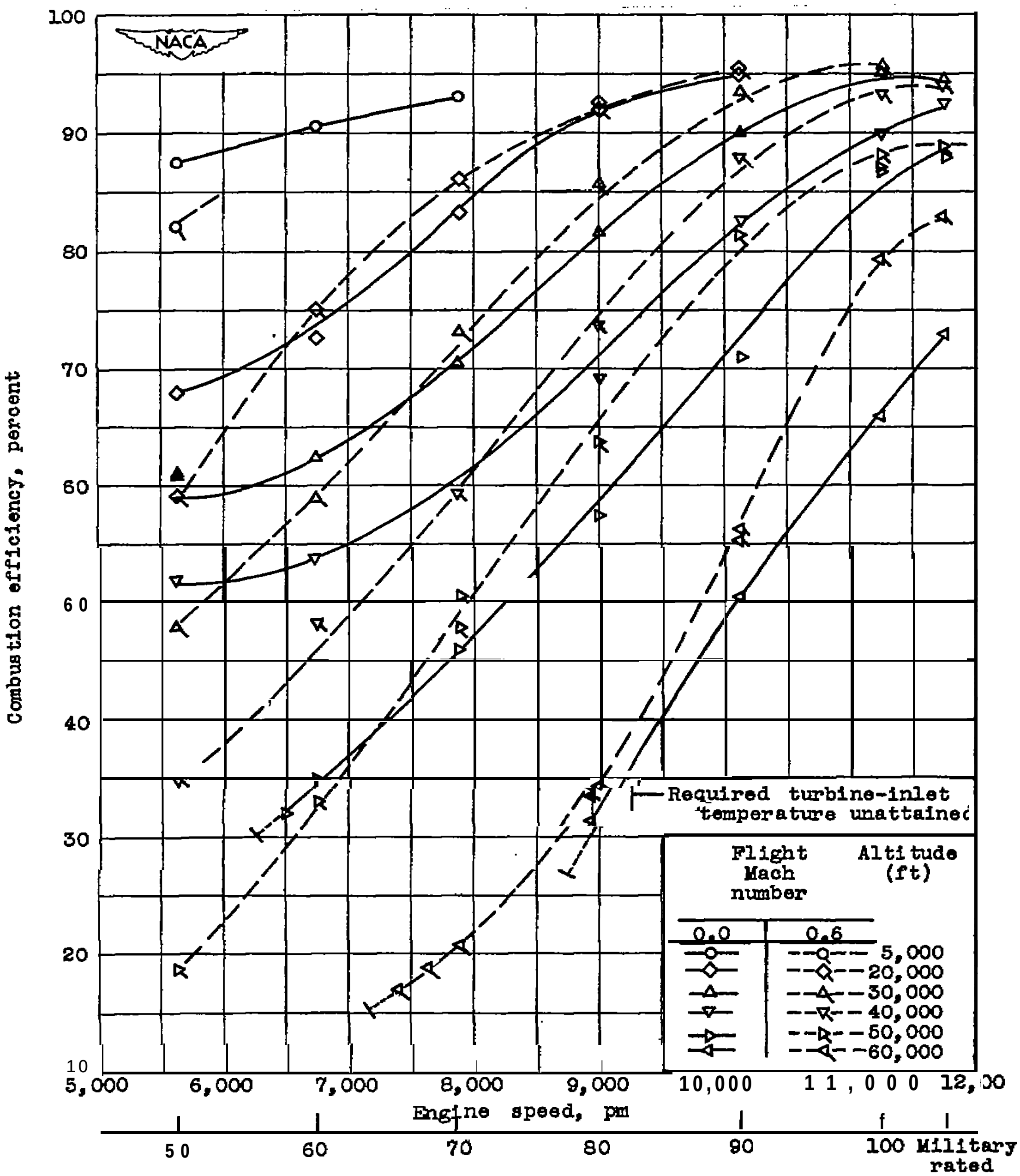
(a) Outlet temperature and air flow. Flight Mach number, 0.6.

Figure 4. - Continued. Control chart for single combustor investigated.



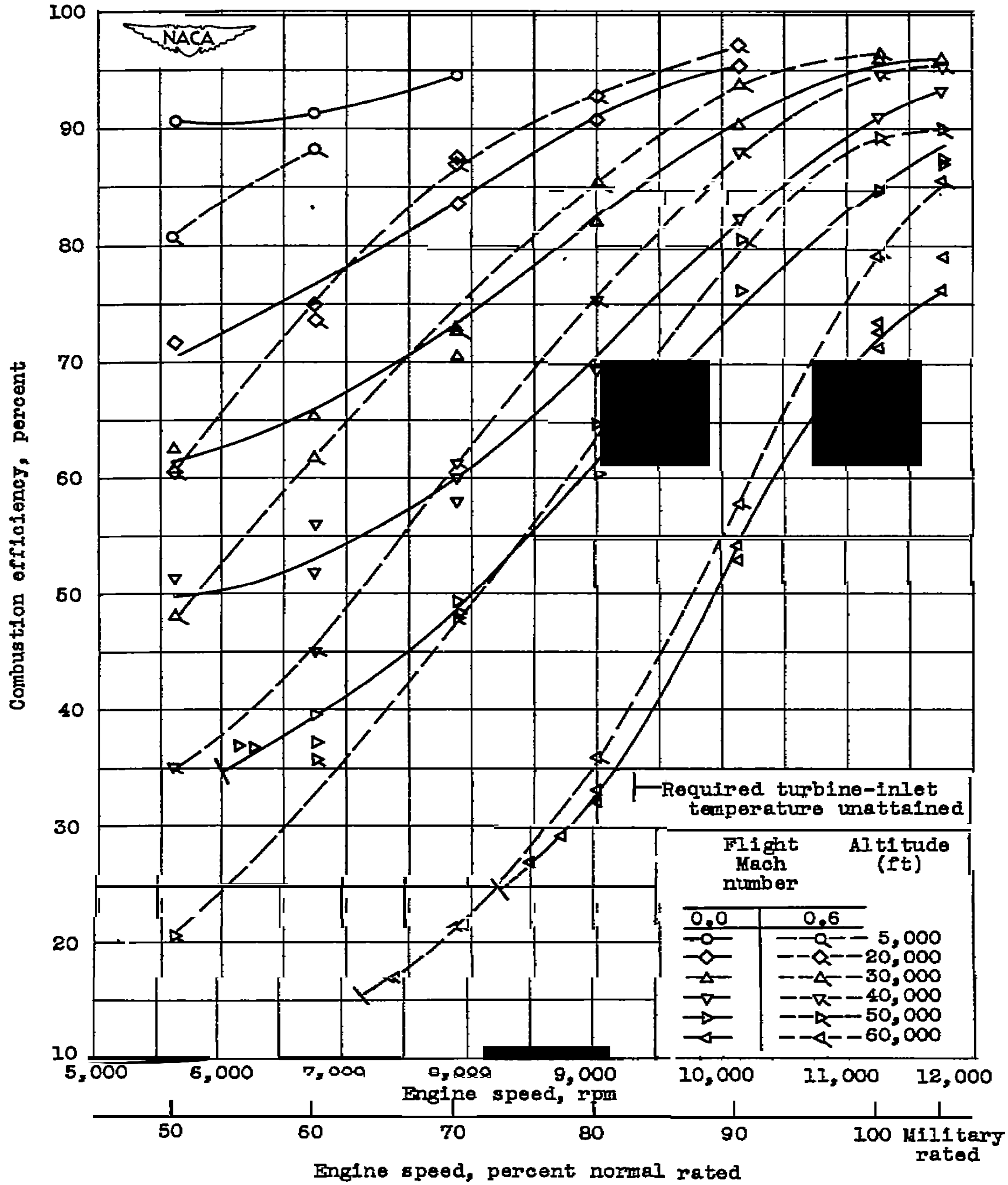
(d) Inlet temperature and pressure. Flight Mach number, 0.6.

Figure 4. - Concluded. Control chart for single combustor investigated.



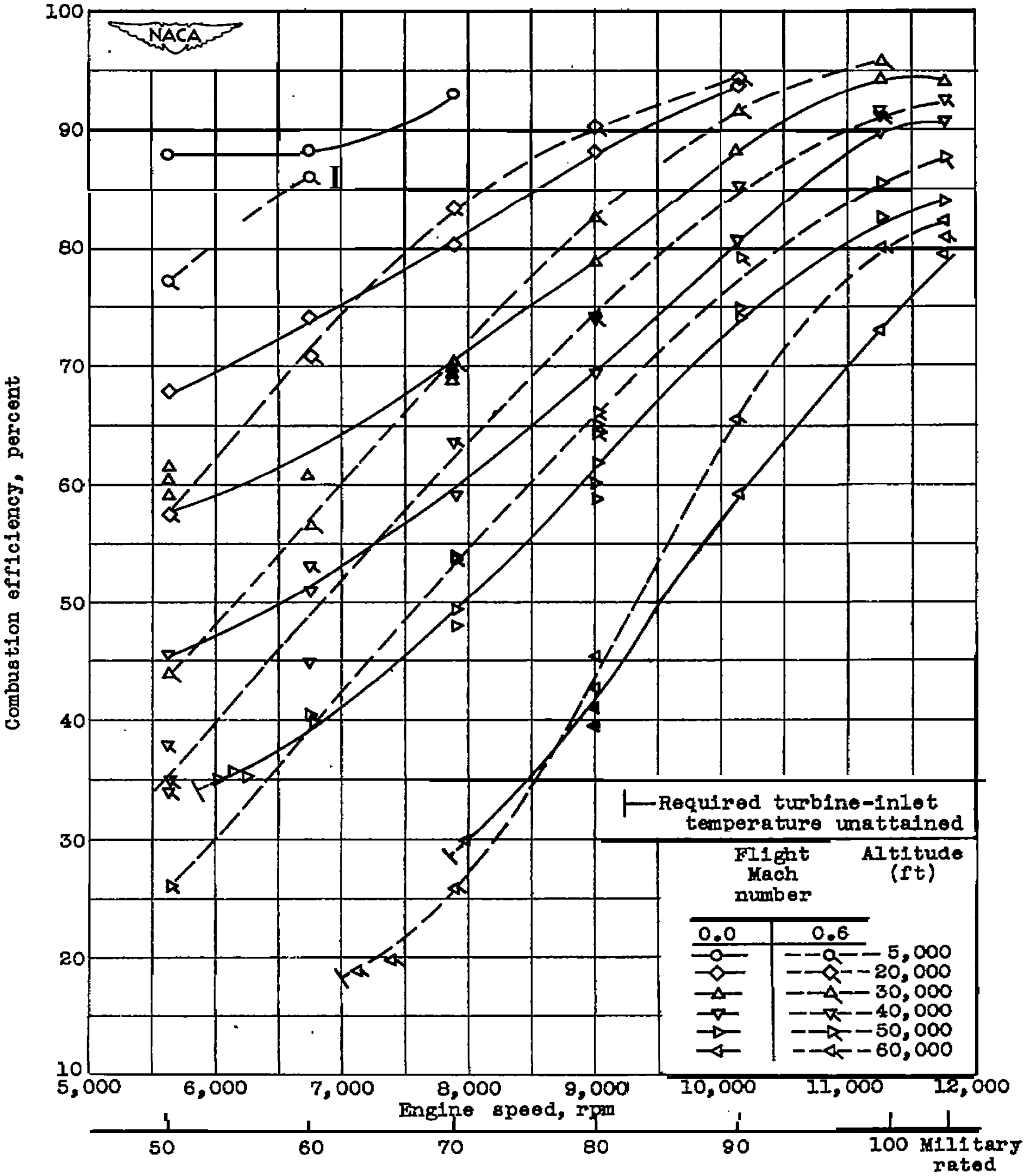
(a) Fuel, AN-F-58 (NACA fuel number 48-249).

Figure 5. - Effect of flight Mach number on combustion efficiency at various altitudes with engine speed for four fuels in single combustor.



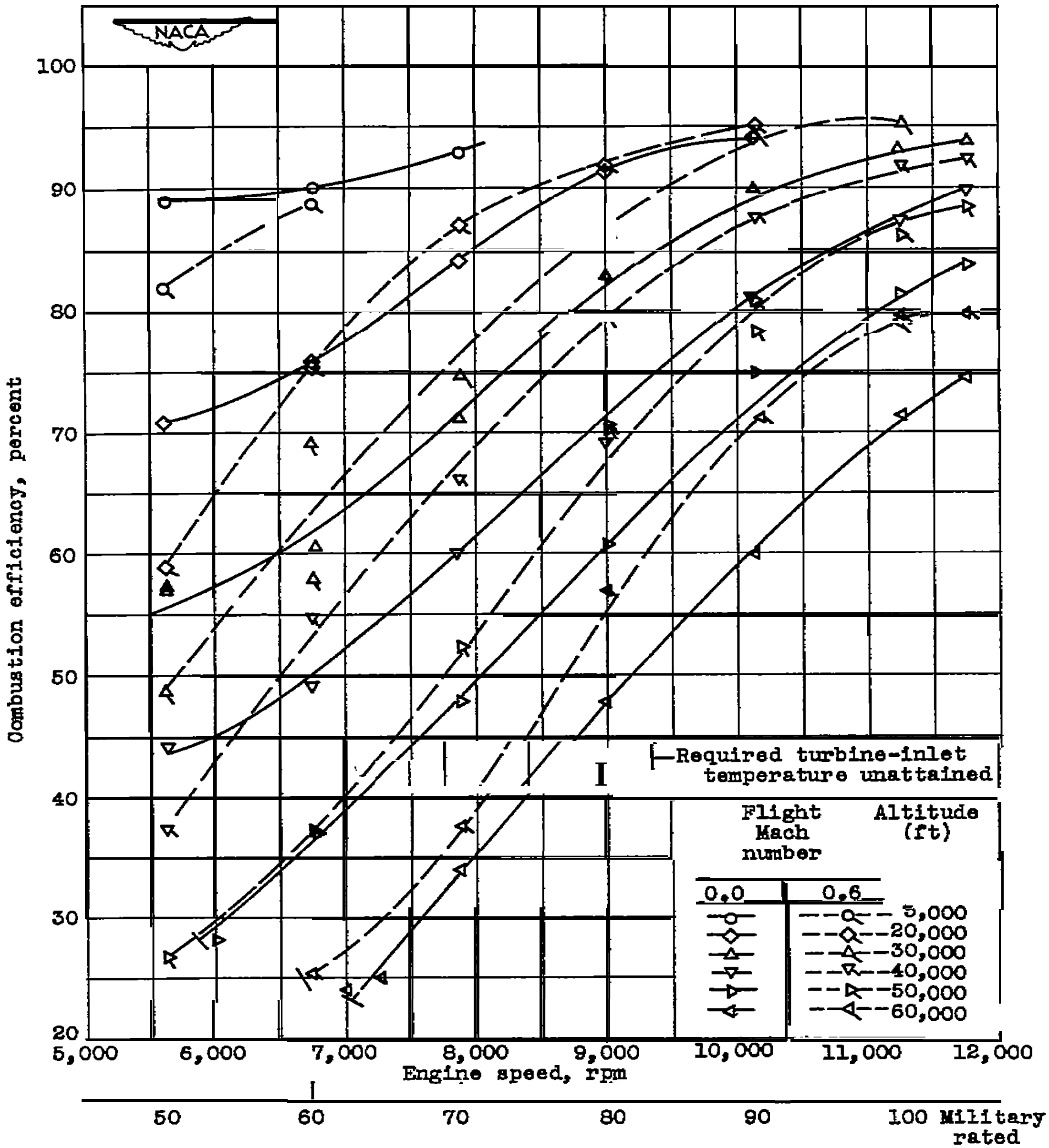
(b) Fuel, AN-F-58 (NACA fuel number 48-258).

Figure 5. - Continued. Effect of flight Mach number on combustion efficiency at various altitudes with engine speed for four fuels in single combustor.



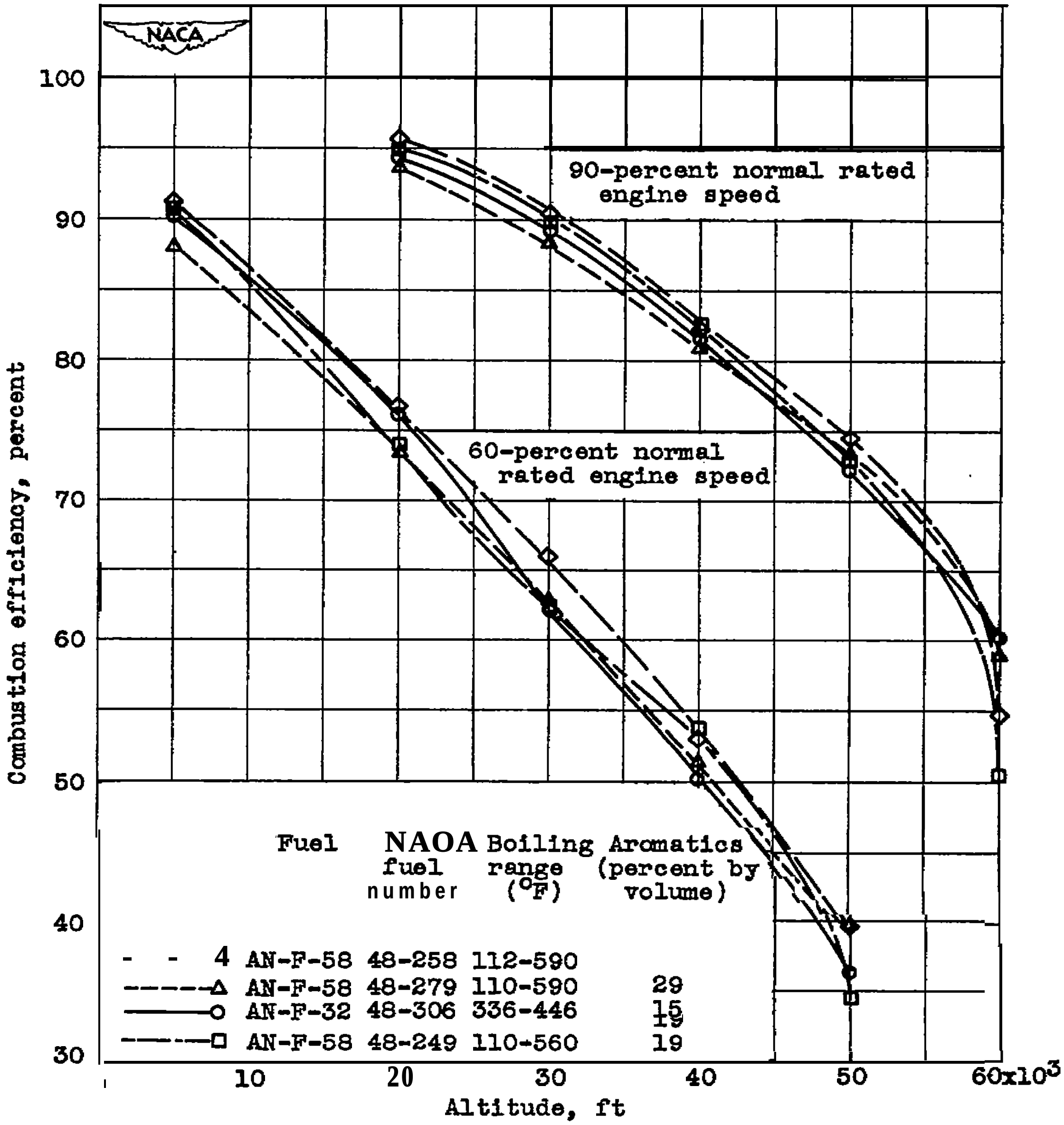
(c) Fuel, AN-F-58 (NACA fuel number 48-279).

Figure 5. - Continued. Effect of flight Mach number on combustion efficiency at various altitudes with engine speed for four fuels in single combustor.



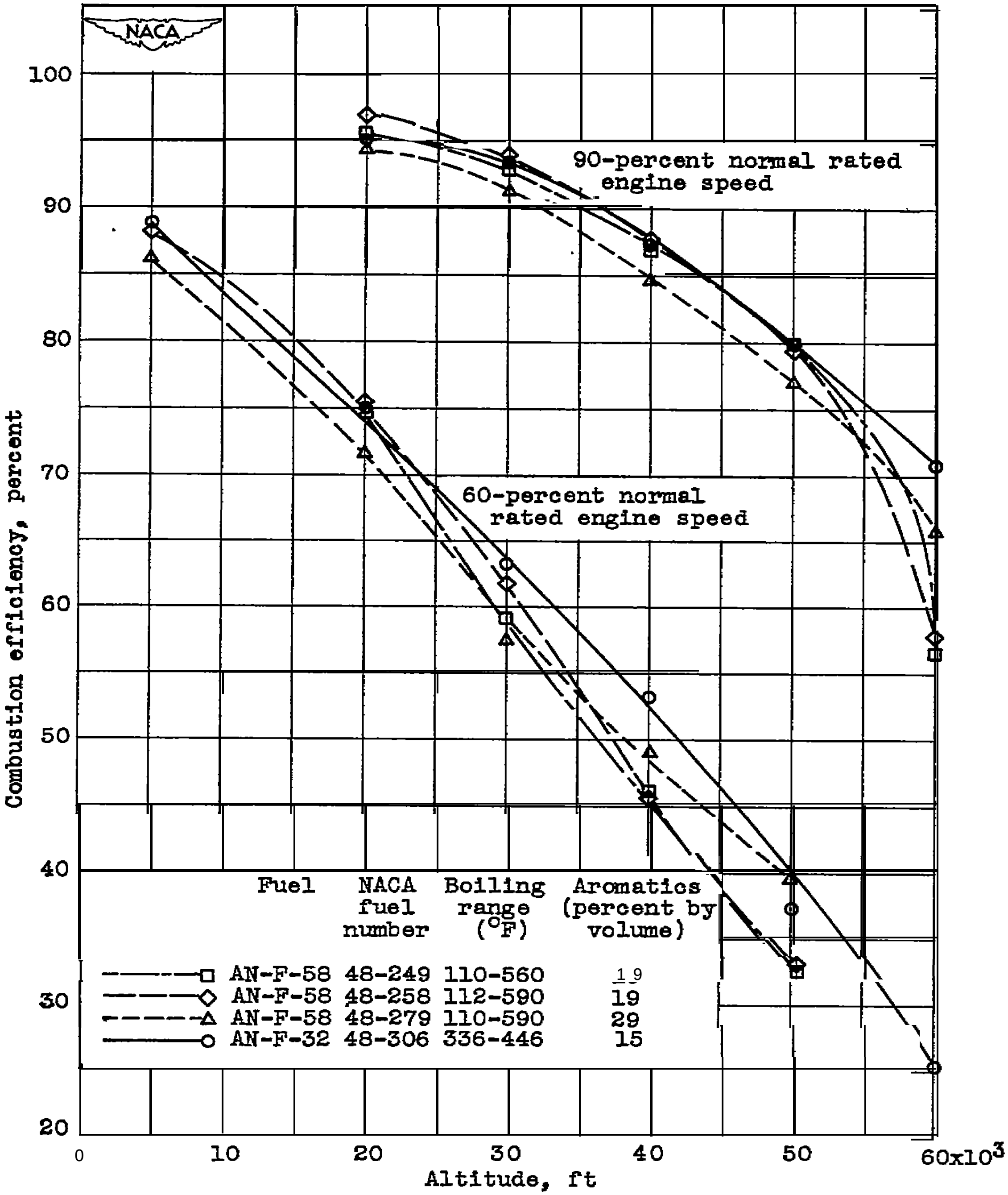
(d) Fuel, AN-F-32 (NACA fuel number 48-306).

Figure 5. - Concluded. Effect of flight Mach number on combustion efficiency at various altitudes with engine speed for four fuels in single combustor.



(a) Flight Mach number, 0.0.

Figure 6. - Variation of combustion efficiency at 60- and 90-percent normal rated engine speed with altitude for single combustor at two flight Mach numbers.



(b) Flight Mach number, 0.6.

Figure 6. - Concluded. Variation of combustion efficiency at 60- and 90-percent normal rated engine speed with altitude for single combustor at two flight Mach numbers.